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Equilibrium and Evolutionary Foundations of Competition and Technology Policy: New Perspectives on the Division of Labour and the Innovation Process

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The ideas in this paper have been aired on several occasions including the British Association for the Advancement of Science meeting in October 1995 and in a subsequent essay in honour of Clem Tisdell. This conference has provided an opportunity to rethink some of the principal arguments in the light of recent developments in the literature.

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> "A country's eminence in a field of science is not a good guide to its economic strength and growth." Carter, C. and Williams, B. (1964) p. 197.

Introduction

The problem addressed in this paper, the relationship between science, technology and economic performance, has a long history and an even more promising future. It is unlikely ever to fall out of fashion and it is unlikely ever to be entirely resolved. For it deals with two immensely complicated and interlocking problems, the nature of economic dynamics in capitalist economies, and the nature of the accumulation of practically valuable knowledge. A distinguishing feature of capitalism in the wide array of unco-ordinated efforts to innovate that are subsequently strongly co-ordinated by market processes. While market competition is an integrating co-ordinating process, innovation is directed at the production of micro diversity. It is this creative dimension, the evolution of business conjecture and market test that makes the operation of capitalism so complex and dynamic. The system is continually being transformed from within, and the essential element in all this is the accumulation of new practical knowledge. This adaptive, learning capability, we claim, rests very largely on the distinctive role of the firm within the system, and the complementary distinctive role of the market form of economic co-ordination. The firm is unique as an organisation in its role of having to acquire and combine many different kinds of knowledge and put them to practical effort. The market is unique as an instituted set of rules that evaluates rival uses of resources and in the process creates the incentives and the opportunities for innovation based challenges to existing activities. The combination is an extremely powerful basis for economic transformation at all levels, from the industry to the nation state. History tells us this beyond doubt (Freeman and Louca, 2001)

This essay treats this topic in terms of three connected themes. The first two involve a critical appraisal of two of the dominant post-war ideas in the field, the linear model of the knowledge-innovation relationship, and the market failure doctrine and its relation to public policy. The third theme is the systemic view of the innovation process and the implications this has for our understanding of the collaborative nature of the innovation process. I conclude with some brief observations on recent policy issues in the UK, particularly the Foresight programme and the matter of tax incentives for R&D.

My argument will be that an effective innovation policy requires recognition that science and technology are distinctive but interdependent branches of knowledge. They are jointly required as inputs into wealth creation, and their effective alignment requires the creation of appropriate technology support and innovation systems, systems which increasingly transcend national boundaries. The chief distinguishing characteristic of such systems is the collaborative involvement of industry (my shorthand for the major user of science and technology) and academia in the execution of knowledge development programmes so that all the relevant and vastly different advances in understanding required to develop innovation are brought together. For a crucial feature of the modern innovation process is the multidisciplinarity of knowledge inputs combined with multiple institutional sources of relevant knowledge. Very few firms can expect to innovate in isolation and the question of how the potential innovator is embedded within, and connects with, the wider matrix of knowledge generating institutions becomes an issue of the first importance for policy. Distributed innovation systems become the context in which policies have their impact for better or for worse. However, innovation systems, like all institutions are not natural givens, they have to be constructed and they develop over time in response to incentives and opportunities. The dynamics of the birth, growth, stabilisation and decline of innovation systems is addressed in the final part of our argument.

I shall suggest that the principal aim of technology and science policy from a systems perspective is to ensure the creation of effective knowledge support systems, which bridge between industry and the science and technology base. By contrast, the principal aim of innovation policy must be to combine the scientific and technological knowledge with knowledge of market opportunities and organisational opportunities. One must recognise that firms, universities and public research bodies are distinctively different kinds of institution each adapted to a specific purpose. It would be as foolhardy to make academic organisations overly commercial, as it would be to make private firms unduly non-commercial. The division of labour between them is not accidental and the central problem of policy is to work with this division of labour and to connect these different agencies together in a more productive fashion. In short, science, technology and innovation policy should be concerned with proper process and not directly with specific creative events, which are inherently unpredictable. The true nature of the problem is the need to accept that the links between science, technology and innovation are as much matters of organisational and institutional design as they are of R&D expenditure. It is this claim that contains the principal implications for innovation policy. In this perspective, the policymaker is no longer an optimising, Pigovian, bureaucrat correcting for the market divergence between private and social costs and benefits. Rather he or she is an adaptive policy maker severely constrained in terms of what is known and at most as boundedly rational as the private agents whose behaviour is to be influenced by policy. The learning abilities of policy makers in an experimental economic system are consequently of considerable importance (Teubal, 1996).

An important logical strand runs through the evolution of policy thinking in recent years. A strand which recognises that if science and technology are funded as national investments the crucial issue is to ensure that those investments yield an adequate return, a return ultimately reflected in enhanced competitiveness, wealth creating potential, and the quality of life. This thread has characterised innovation policy in the USA and Europe as well as in the UK. Indeed, to the extent that new institutional arrangements ensure a more effective return is obtained from science and technology; this of itself provides the most powerful of arguments for increased expenditure on research and development of all kinds. In short, science and technology have become a victim of diminishing returns to effort. Even before the end of the cold war, their role in wealth creation was subjected to critical scrutiny. The case for spending more on science and technology depends on a greater effectiveness of innovation policies more generally, and with the prospect of greater budgetary stringency in the European monetary area this makes the case even more pressing.

In raising the question of the return to R&D, I cannot avoid introducing the closely related question of the relation between innovation and competition treated as coupled dynamic processes. The generation of practical knowledge is inseparable from the wider context of economic activity and this implies that innovation policy and competitive policy are complementary elements in the innovation process. In each case the deep issues relate to how activities premised upon the division of labour are to be appropriately co-ordinated.

The Linear Model and The Distinctiveness of Technology and Science

We can begin by noting two possible justifications for the public support of fundamental research in science and basic technology. The first sees their output as a cultural, consumer good, which enlightens and entertains the public at large. This is, of course, a perfectly valid viewpoint: the discovery of a new star or a hitherto unknown species of plant are, in these terms, no less meritworthy, than the performance of a new symphony. They enrich and enliven the understanding of our world. Sadly but understandably, this is not a style of argument which is usually appealed to when justifying public support of science and basic technology[1]. Instead, a second view, an instrumental view, has dominated. Promoted and accepted by government and the science establishment, this argues that such fundamental knowledge is an investment which generates a more than compensatory return in terms of wealth creation or improved living standards via, for example, medical advances or better control of the environment. This is so even though the linkages may be impossible to pin down in an a priori fashion. This modern, science based investment argument was a theme first made public by the Vannevar Bush report 'Science - The Endless Frontier' published in 1945 (although the 'golden egg' view of science goes back at least to Francis Bacon in 1635) in which the strong claim was made that

> "New products, new industries and more jobs require continuous additions to knowledge of the laws of nature ... essential new knowledge can be obtained only through basic scientific research" (my emphasis).

As Wise (1985) has suggested this is the original statement of the modern, linear or production line model of the innovation process[2]. And in the UK as late as 1968, the Central Advisory Council for Science and Technology was able to claim that basic science is the origin of "all new knowledge without which opportunities for further technical progress must rapidly become exhausted" (my emphasis). This, by now discredited, view was nonetheless extremely influential for about two decades after 1945 as were its twin corollaries that technology stood below science in a hierarchy of importance, that technology was merely applied science, and that the flow of new scientific knowledge would increase in proportion to the funds allocated to basic research (Wise, 1985; Keller, 1984).

It is perhaps worth pointing out that this perspective on science was articulated with some force by Alfred Marshall in the immediate period following World War I. In his Industry and Trade (1919), he argues as follows:

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[1]Although, of course, there is widespread concern, in the UK at least, in relation to public understanding of science, and of science as an element in school curricula. I treat basic technology as equivalent to basic science in that both are concerned with the search for fundamental principles that help connect and classify different phenomena. Not all technology can be equated with knowledge of specific applications.
[2]Branscomb (1993) also refers to this as the pipeline model of the science technology relationship.

> "History shows that almost every scientific discovery, which has ultimately revolutionised methods of industry, has been made in the pursuit of knowledge for its own sake, without direct aim at the attainment of any particular practical advantage: Universities are the proper place for such pursuit of "pure" science …" (p. 100)

Perhaps not surprisingly for an economist who understood the full significance of increasing returns and the division of labour, we find in Marshall's discussion an emphasis upon different classes of laboratories (pure science, technological, quality control) and of the importance of teamwork to combine different skills in the advancement of knowledge. In all but name, Marshall can be said to have described elements of an innovation system; he entirely understood the importance of the pure scientist "keeping in touch with some of those industries, whose methods might be improved by increased knowledge of the properties of the products which he is studying" (p. 100). Within this perspective, Marshall clearly saw a role for research collaboration between firms, ideally with some state support to keep an eye on possible anti-competition abuses of the consumer, and, indeed, he was fully aware that expensive laboratories could hand a competitive advantage to larger firms. Marshall is amazingly modern in his treatment, Industry and Trade, is full of references to the importance of national differences in the institutions of science and technology and to the theme that "thought, initiative and knowledge are the most powerful implements of production". Thus, it seems that the Baconian tradition of the utility of science has had a powerful sway on thought and policy long after it was first enunciated[3]. It is, however, a view with serious limitations.

The first and crucial point about this instrumental view is that at best it covers only a small fraction of the activities involved in the innovation process. The return in terms of innovation and wealth creation depends on a wide range of other non-scientific and non- basic technological activities and expenditures of a quite different kind, including those to achieve organisational change. Unless these activities are carried out effectively to transfer science and basic technology into exploitation, the economic return to extra scientific expenditure is likely to reduce very rapidly. Whether we take a "demand pull" or a "science push" approach to the linear model, the weaknesses remains the same, complementary assets of many different kinds have to be accumulated to turn fundamental knowledge into economic wealth.

[3] Prior to the industrial revolution one should note.

Innovation policy must necessarily have a broader focus than either science of technology policy.

The second flaw in the production line model concerns the failure to distinguish between the different attributes of science and technology. A wealth of recent research has established quite clearly that science and technology are largely independent but mutually beneficial bodies of knowledge, created by different processes of accumulation within distinctly different communities located in different institutional contexts (Layton, 1987; Vincenti, 1990; Keller, 1984; Faulkner, 1994). Both solve problems, are creative, imaginative, but the problems addressed are quite distinctly different and the communities that identify and solve those problems respond to different incentive mechanisms[4]. In broad terms, science is naturally academic, its legitimate output is additions to the existing stock of knowledge about natural phenomena for their own sake. Science is open, the outputs are widely diffused through an international publication culture and the primary incentives are in terms of priority in publication and the influence of ideas. Conversely, technology is naturally practical, its legitimate outputs are artefacts and the knowledge by which they are designed, constructed, operated, and intrinsic worth is to be judged not by the law-like truthfulness of the knowledge but by its practical utility. Moreover, while it is essential to the replicability of scientific results that they be codifiable, much of technological practice rests in a tacit realm only easily communicated through observation and trial, not publication. This is why one important dimension of technology concerns the people embodied skills of the practitioners. An immediate consequence of this is to deny that technology is merely science applied. Rather technology is a distinctive body of knowledge, ranging from the basic to the applied, with its own operating principles and norms for design activity and its own distinct communities of practitioners, it is essentially local knowledge (Antonelli, 1998; Constant, 1980; Layton, 1987). Moreover, as many scholars have observed, technologists have designed and operated artefacts well in advance of a scientific understanding of the phenomena observed and their labours have directly stimulated the search for an understanding of the natural laws that underpin the operation of the artefacts. Equally, the technologies of instrumentation have played a major role in expanding the experimental boundaries of science.

[4]Faulkner (1994) provides a perceptive and thorough review of the more important aspects of the science:technology relationship, and the links with innovative activity.

There is another way of looking at the science technology relationship which is illuminating. It is not difficult to see that if the choice of technological problems were decided randomly then there would not be much progress. The number of combinatorial possibilities is simply too vast and so individual discoveries do not have an impact unless they connect with other accepted facts and theories. So technological advance, like scientific advance, is necessarily cumulative, within a set of given design principles it proceeds along paths which, at least ex post, seem to involve their own inner logic. Technical advance involves guided variation in which knowledge of where to search in the set of possible options is absolutely crucial to rapid advance (Metcalfe and DeLiso, 1998). Here lies a key contribution of science, providing knowledge of where to look, and crucially where not to look in advancing technology, and in providing both tools for investigation and skilled practitioners (Vincenti, 1995; Pavitt, 1991). Better scientific understanding is a contributor to more effective technological search (Nelson, 1982; Gibbons and Johnson, 1974) and it reduces the cost of technological advance. It is not helpful, consequently, to claim that science leads and technology follows or *vice versa*. They are distinctive mutually supporting bodies of knowledge created for different purposes. That they illuminate one another is scarcely surprising, and the interesting question is how this process of division of labour and reciprocal enlightenment works and is institutionalised[5].

It is this insight which lies behind the recent illuminating book by Stokes (1997). He argues that a great deal of the practice of modern science cannot be located at the mutually exclusive, extreme ends of the basic to applied spectrum. Rather much of what is called basic science is in fact a fundamental exploration into the properties of nature with an explicit awareness of their potential application in practical contexts. An unwillingness to accept this simple fact of application directed, fundamental enquiry lies behind many attempts to develop overly simple taxonomies to record scientific activity (e.g. the distinction between curiosity oriented and mission oriented research), behind the ill-design of the organisation which carry out science, and in the ideology of the separation of the relative roles of public and private sectors in promoting science and technology. Indeed the OECD picked up this theme in a complementary fashion when it rightly argued for the importance of transfer

[5] See Narin et al (1997) for evidence of the increasing citation of basic science papers in industrial patents. Notice carefully that a closer degree of interdependence between patents and scientific papers, particularly strong in the biomedical and chemical areas, does not establish that there is a closer link between science and economic growth. There is a missing link. Namely the translation of patents into competitive innovations. As this paper argues there is much more to innovation than scientific knowledge.

sciences (engineering, pharmacology, agronomy, computing, medicine) bridging between fundamental work and application within the scientific enterprise (OECD, 1992)[6]. There are two lessons to be drawn from this: many different kinds of knowledge have equal status in the innovation process, and the design of the institutions of science and technology is of great practical significance for the link between science and innovation. In this regard, Stokes's work is a devastating critique of the Bacon/Bush view but it leaves untouched two further and important issues in relation to the science-innovation relationship.

[6] The transfer sciences are precisely the sciences which constitute Pasteur's Quadrant in Stokes's analysis and indeed they fit easily into the Gibbons et al notion of mode-2 knowledge production. As the OECD report rightly emphasises their hybrid, bridging role does not imply that they lack coherence. The communities of practitioners involved are usually formed into distinctive professional associations (OECD, 1992, pp.35-37).

The first of these follows from the practical directedness of technological knowledge and its close interaction with economic and social stimuli. What technologists and engineers design and construct in the innovation process has to pass the test of economic viability and social acceptability. Design is ultimately normative: what is the best, read most profitable, combination of materials turned into components and linked into systems of varying scales of grandeur which reduce costs to a minimum or raise product value to a maximum[7]. Such an approach, dependent on the specific economic and social context, has no meaning when one is seeking for the timeless truth about a natural phenomenon.

Equally important is the fact that many technological advances flow from experience gained in using and producing specific artefacts. This dependence of technological advance upon practical experience gained in the diffusion and integration of artefacts into the economy is a quite distinctive feature of technological change which scientific advance does not share. One need hardly add that practical experience is accumulated by quite different processes than is scientific knowledge. Yet both are vital for the innovation process. Consequently, markets and technologies co-evolve and the way in which technology develops is strongly shaped by the rate and direction of market application. This is, of course, one of the key implications of the product/technology life cycle literature (Utterback, 1994) and the modern analysis of the diffusion of innovation. To know what consumers will be willing to pay for is no less significant a kind of knowledge than the scientific and engineering knowledge which underpins any particular artefact. Sadly, the role of this demand related knowledge is almost entirely neglected in the current theory of innovation.

Now in putting these observations together we recognise that a number of scholars have found fault with the linear model for its failure to recognise the recursive, autocatalytic nature of innovative activity (Langrish *et al*, 1972; Kline and Rosenberg, 1986). I want to emphasise a different point. It is that quite different processes operating in quite different organisational contexts accumulate the different kinds of knowledge essential to the innovation process. Science and basic technology is guided by theory and experiment, and carried out primarily, but not exclusively, in universities and public research laboratories.

[7]Petroski (1996) lists the following facets of engineering activity: design, analysis, failure, economics, aesthetics, communication, politics and quality control – to name but a few (vii).

The nature of the knowledge and its mode of accumulation vary from discipline to discipline. Engineering and applied technology are relatively less theory driven, they depend more on trial and error accumulation in practical contexts, and failure in use is often a significant knowledge generating event. Such knowledge is accumulated primarily but not exclusively in firms. Market knowledge is devoid almost entirely of theoretical foundation but depends on conjectures which are tested and revised in the far more amorphous market place. Naturally, the different kinds of knowledge are accumulated over different timescales and in institutions specialised to develop that kind of knowledge. It is this insight which underlies the increasing emphasis upon innovation systems. Many different kinds of knowledge are required to innovate and be competitive, and this requires some system of interaction and communication. Division of labour in producing knowledge implies co-ordination in putting knowledge to practical use, and co-ordination is a systemic instituted property (Coombs *et al*, 2001).

The Failure of Market Failure

The development of an economics of information and knowledge in the 1960s has paved the way for a particular rationale of innovation policy no less inaccurate and misleading than that embodied in the linear model of innovation. Central to this rationale is the idea that markets in relation to knowledge and information have an inherent tendency to produce socially inefficient outcomes, inefficiencies, which provide the justification for failure correcting public policies. This has proved to be a powerful set of ideas for shaping policy debate, particularly concerning the public support of university based science and technology that are far from market application. I shall argue that it has been a far less useful means for designing specific innovation policies. The reason is clear, the idea of a perfectly competitive allocation of resources (the doctrine of Pareto optimality) on which the idea of market failure is premised is a distorting mirror in which to reflect the operation of capitalism. This doctrine seriously misreads the nature and role of competition in modern societies through its failure to realise that capitalism and equilibrium are incompatible concepts and that innovation precludes equilibrium. We can explore this claim in more depth by considering the phenomena advanced as types of market failure in relation to the production and use of knowledge in general.

The most transparent and unproblematic ones are imperfect property rights and genuine uncertainty. The former has long been recognised as a justification for patent and copyright systems; and rightly so, on the grounds that imitators derive economic benefit from unprotected new ideas without rewarding properly the creator of these ideas. It follows that the incentives to invest and innovate may be dulled by the existence of unrequited knowledge spillovers. In principal, the answer is to the affirmative but in practice, the issue is less clear-cut, and policy is about practice.

The problems here are two-fold. It is not spillovers per se that damage the incentive to invest in knowledge production but a presumption of instantaneous and complete spillover, an unlikely state of affairs for reasons which become clear below[8]. Absent this, and the existence of many practical ways that firms have developed for protecting knowledge acquired privately, and it becomes clear that inventors and innovators may still gain an adequate return from their investments without patent protection. In some situations, patents and copyrights are important sources of provisional, temporary protection but these cases by no means cover the whole range of innovative activity[9]. Secondly, this doctrine is far too negative, not all spillovers are between direct competitors. Spillovers have positive benefits in stimulating the creation of new knowledge, which should not be underestimated, indeed, this is why patents are designed to put inventive ideas in the public domain. There is no reason why an alert firm should not gain more than it loses from the unplanned flow of information and so enrich its innovative capacity. In this regard, information spillovers are to be encouraged and one might expect firms to try to manage this process through links with other knowledge generating institutions, which is precisely what we observe in practice[10].

[8] I note in passing that what is spilt is information (messages) not knowledge. The knowledge content of any information flow is, of course, notoriously unpredictable as any university examiner knows only too well. That this is so is essential to the emergence of novelty.

[9] Those industries where other aspects of public regulation force innovative knowledge to be placed in the public domain well in advance of exploitation provide important examples. Health and safety legislation in relation to the pharmaceutical/medical industry is an obvious case in point. In regard to patent systems there is a long-standing debate on their merits and demerits, particularly in regard to the duration of patents and their scope.

[10] Hence the increasing volume of work which points to the role of knowledge spillovers in productivity growth. Cf. Griliches (1998) for an authoritative treatment.

What is interesting about the idea of property rights in commercially valuable knowledge is that they sit side by side with very imperfect property rights in economic activities more generally[11]. Copy my invention and I can pursue you in the courts. Make a better but unrelated equivalent and there is nothing I can do except compete. Indeed if it were otherwise, it is difficult to see how capitalism could have been the source of so much economic change and development. This means of course that competition is a painful process. Investors, whether their assets are in paper titles or human skills, are ever open to the erosion of their worth by innovations made by others. The fact that on average standards of living are enhanced by innovation should not blind us to this fact and to the inherently uncertain nature of innovation related economic processes. From a policy viewpoint, one immediate implication is that the scope of patents should not be drawn too broadly for this simply limits the ability of others to explore the design space with which any invention is associated. Thus, broad patents have the potential to damage the creativity of the capitalist model (Merges and Nelson, 1997).

Consider next the second broad source of market failure. In modern capitalism, genuine uncertainty is 'built in', as it were, and its consequences for the willingness to invest in innovation are far more difficult to cope with. However, the idea that innovation related risks may be accurately computed, priced and used in actuarial calculations of expected costs and benefits is fanciful in the extreme. Innovations like all discoveries are unique events for which the probability calculus is an inappropriate method of analysis. Much decision making about knowledge creation is at root an act of faith, it is a matter of conjecture with necessarily unpredictable time delays between knowledge creation, application and market testing. Moreover, it is not at all obvious that the process of accumulation of scientific or technological knowledge is any less hazardous than the accumulation of market knowledge (Callon, 1994).

[11] It is worth noting that competition authorities in the UK have taken a dim view of firms which refuse to grant licenses to exploit their patents and of attempts to use licenses to distort the competitive process.

One immediate consequence of true uncertainty is what economists call asymmetric information, an imbalance of knowledge, for example, between firms and potential suppliers of capital or customers and between R&D managers and a firm's board of directors. Neither potential lenders nor customers nor, for that matter, civil servants, can accurately judge the credibility of innovative claims made by a firm nor can boards of directors always accurately evaluate the claims of technical personnel. Firms then find it difficult to get others to share the uncertainties of technology development in short, it is difficult to trade the uncertainties associated with innovation projects. To some degree, this puts large firms at an advantage in that they can pool the indeterminacies from a portfolio of projects, and it helps us understand the pressures towards more collaborative work in R&D and towards mergers and acquisitions between complementary technology-based companies. One consequence of all this is that many knowledge transactions are mediated by a range of non-market methods, primarily involving networks and other forms of arrangement between organisations and individuals, procedures which build confidence and trust and work to limit the damaging consequences of uncertain asymmetric information.

However, this scarcely calls for the appellation 'market failure'. Quite the contrary, asymmetric information is an essential element in the working of a competitive, capitalist economy. The uncertainty which follows arises not from games with nature but from the very pursuit of innovation by rivals as a route to competitive advantage. It is simply perverse to label as market failures phenomena which are integral to the competitive market process and which give modern capitalism its unique dynamic properties. Nor is there any obvious way that policy could 'correct' for asymmetries, they are simply part and parcel of the process of innovation and economic change. The fundamental fact is that profits follow from the deployment of ideas that others do not have and so the whole system dynamic is premised on the generation of unquantifiable uncertainty. One cannot sensibly argue that the economy would perform better if innovation related uncertainties were reduced for the only way to reduce these uncertainties is to reduce the incidence of innovation and thus to undermine the mainspring of economic progress.

Consider thirdly, the so-called public good problem. All knowledge has the intriguing property that it is used but not consumed in its using, and that once discovered, it is in principle useable by any individual on any number of occasions to any degree. In the terminology of economics, there is non rivalry and non-excludability of knowledge. So, runs the argument, the incentives for any one individual to reveal how much they value an item of knowledge are deficient, with adverse consequences for the willingness to pay and the establishment of predictable demand relationships. Of course, this links with the spillover argument, for it is the non-rival nature of knowledge that makes spillovers possible. Notice, however, that the public good dimension does not imply that the communication of information, that is to say the representation of knowledge in some message format, is costless. There is much more to the transfer of knowledge than the costs of communication in the narrow sense. In many cases the interchange of knowledge requires communication between "like minds" only open to those who have acquired comparable abilities to understand the significance of new scientific and technological information. Knowledge is a public good in the sense of non-rivalry in use but it is not usually a free good and this is particularly true of complex scientific and technological knowledge. Hence the oft remarked point that to benefit from the information generated by others one must make one's own substantial investment in scientific and technological capability (Mowery and Rosenberg, 1989; Rosenberg, 1990; Hicks, 1995, Veugelers, 1997).

Scholars interested in innovation have for many years drawn upon the useful Polanyian (1958) distinction between tacit and codified knowledge, the former embodied in human skill and practice, the latter in material form. Tacitness, is presented as a reason why information does not flow freely, while codification, is seen as a means to make information public. Thus, Callon (1994) is quite right to point out that the limits to excludability depend upon the way in which information is embodied in different communication media, and that access to any particular knowledge depends upon complementary assets being accumulated to give the capability to maintain and use knowledge based statements. However, it is important to recognise the point that the division of knowledge into mutually exclusive categories, codified and tacit, does not uniquely reflect properties of the knowledge itself. Rather, it is in part an economic decision dependent on the scale on which the information is to be used and the costs of codification. It is thus inextricably linked with the division of labour in the economy more widely, as I shall explain below (David and Foray, 1996). To summarise, the weakness of the public good model of knowledge is that it places the transmitter and recipient of knowledge on the same footing and ignores entirely the importance of mode and process of intercommunication. This is simply not helpful. It may be cheap to transmit information but the interpretation of information, its translation into practical knowledge is never costless.

I turn now to a fourth broad class of market failures those that relate to indivisibility and increasing returns to exploitation. Fundamental to the economics of knowledge production and dissemination is the fact that the exploitation of a discovery is subject to increasing returns: the fixed cost of producing an item of knowledge can be spread over a greater volume of output as it is used more widely and more intensively in the production process. This is an important consequence of non-rivalry. However, since one cannot innovate on the basis of a fraction of a technology or a quarter of a scientific fact, there is necessarily an indivisible cost of creating the knowledge behind an innovation. This fixed cost makes the ex ante valuation of knowledge virtually impossible since the scale of its application cannot normally be predicted, and, incidentally, means that marginal cost pricing of innovations would prevent the costs of knowledge creation from being recovered. Furthermore, every investment in innovation now requires its own minimum scale of exploitation if an adequate return is to be achieved. The result of these considerations is the complete inability of the perfectly competitive model to provide guiding principles in a world where firms are required to innovate in order to compete (Stiglitz, 1994). The fixed costs they must incur unavoidably mean that such markets will at best be imperfectly competitive. The only way the fixed costs of knowledge production could be covered independently of prices ad outputs would be for public laboratories to develop that knowledge or for all private research and development expenses to be fully subsidised from the public purse. This is not a model for innovation likely to commend itself outside of very special cases such as metrology and public technical standards in general.

The public support of university science is thought to constitute the best case for the market failure argument on grounds of uncertainty, appropriability and publicness. Even here, the matter is not clear-cut. For by no means all university research in science and technology is funded by government, and of that which is, a proportion is directed at meeting the mission objectives of government agencies in such areas as defence or health. Conversely, non-academic organisations carry out a substantial portion of work on fundamental science and technology; indeed firms can often boast far more advanced research facilities than can universities[12]. Moreover, it is not obvious that the primary motive for universities is the production of knowledge in the abstract. Rather, the production of scientific knowledge is an input into the production of qualified scientists and technologists, and if a “market failure” is to be found it is with respect to the market for skills not the market for knowledge.

It is when we turn to innovation in practice that the difficulties multiply. Leaving aside the well recognised imperfections which governments can be subject to when they intervene, backing the wrong horse too quickly or maintaining programmes long after the evidence against continuation is conclusive (Walker, 2000), it is clear that market failure as a policy framework leaves much to be desired (Metcalfe, 1995a, 1995b). The logical underpinning it provides tells us nothing about the design of policy instruments or their appropriate method of implementation or the areas that are most appropriately in need of support in their attempts to innovate. Is the focus to be on new knowledge, new skills or new artefacts? Is it to be concerned with design, with construction or with operation? Is it to focus on the creation of innovation or upon the diffusion of innovation? The answers to these questions could generate very different policy initiatives. Yet, the information to provide the answers is simply not available to the policy maker or for that matter to anyone else. The policy maker cannot become the innovator and so the effective judgement of the relevant market failure is not possible. The market failure framework, despite its formal elegance, is an empty box.

[12] Narin et al (1997) find that of the US scientific papers cited by US industrial patents only 50% came from academic sources while 32% came from scientists working in industry.

What is Missing: Competitive Process and Increasing Returns

Competitive Process

If we reflect on why the market failure doctrine has produced little practical resonance with the world of science, technology and innovation, the answer is not difficult to find. A framework of thinking built on the idea of an efficient equilibrium in the allocation of *given* resources to *given* ends cannot come to terms with the essence of capitalism, its restless, unpredictable nature. Better to start from a different perspective, one that recognises economic activity as a cumulative struggle against ignorance, not as an unfortunate lapse from a world of perfect and perfectly foreseeable knowledge. This different perspective is consonant with evolutionary theories of economic change and with competition as a dynamic discovery process driven by rivalry between finely detailed differences in behaviour. In such a view, the roles of markets is to co-ordinate and evaluate the rival business conjectures and so guide the economic change we (partially) measure in raising standards of living. This involves adaptation to new opportunities, new needs and new resources and it is this function that market institutions perform: they are to be judged not by the canon of Pareto optimality but by their openness in stimulating and adapting to change (Metcalfe and Georghiou, 2000).

Thus, the central weakness of the market failure approach is not its lack of precision but its attempt to establish a policy perspective within the confines of the static equilibrium theory of markets and industry. Each of the market failure arguments identify significant features of the production and use of knowledge but these features have their full impact only in relation to the dynamic nature of the competitive process. Economic progress depends on the ongoing creation of private, asymmetric knowledge which is sufficiently defensible to justify the original investment. How this works out is ultimately a matter of competition, and competition requires active not passive behaviour and the ability to gain access to privileged knowledge is at its core. Competition depends upon the search for competitive advantage, and the development of new products and processes is the principal way this is achieved in modern capitalism. The imperfections identified in the market failure approach are to be viewed in a different perspective, as integral and necessary aspects of the production and dissemination of knowledge in a market economy. From this perspective, it is surely perverse to call them imperfections or market failures. This is, of course, not a new point: for those who have studied Schumpeter they are the natural features of an economic process driven by creative destruction. Another way of putting this is to say that without asymmetries of knowledge and the correlated uncertainties and indivisibilities the competitive process has nothing with which to work. The quasi-public good nature of knowledge, indivisibility and increasing returns, the inherent uncertainties of creative, trial and error processes and the imperfect nature of property rights in knowledge are essential if market capitalism is to function. They are not imperfections to be eliminated by policy.

Several important themes now fit into place in a way that is impossible with the market failure doctrine. First, and foremost, among them is entrepreneurship, a phenomenon which has no meaning in economic equilibrium of any kind. Entrepreneurs introduce novelty into the economy, they disrupt established patterns of market activity, they create uncertainty, and they provide the fuel that fires the process of economic evolution. To act they need, and indeed create, privileged access to knowledge, entrepreneurship and asymmetric information are inextricably linked.

Secondly, the reward to entrepreneurship is the differential economic reward which comes from introducing economic improvements. Such abnormal rewards are not always the consequence of market imperfections, they do not necessarily reflect the undesirable use of market power; they are instead the rewards to superior performance and are to be judged as such. It is a view that abnormal profits are the socially undesirable consequences of market concentration that is the real Achilles heel of the market failure approach and which denies it anything useful to say in the appraisal of knowledge-based, innovative economies.

It is this perspective of competition and innovation as coupled dynamic processes, which provides us with a framework to formulate innovation policy. Innovations create the differences in behaviour which we identify as competitive advantages, and the possibility of competition provides the route and the incentives to challenge established market positions. Moreover, to the extent that market institutions function properly, firms with superior innovations will command an increasing share of the available scarce productive resources, the process which is the link between innovations in particular and economic growth in general[13].

[13] As an aside here, we note that competition is not to be judged by market structure. Two rivals may compete far more intensively than many. The way to judge the efficacy of competitive arrangements is to consider the degree to which rivals can gain market share at the expense of each other and the degree to which they are innovating in the pursuit of competitive advantage.

Lest this appear dangerously Panglossian we should add immediately that the market process is quite capable of putting barriers in the way of innovation. Firms may have every incentive to gain competitive advantage improperly by distorting the competitive process rather than by innovating. Through creating barriers to entry or by imposing constraints upon the freedom to choice of their customers, the market selection process may be distorted in undesirable ways. From this follows the importance of legislation on restrictive practices and competition policy more generally. Not in terms of a concern with price-cost margins or excessive (!) market shares but rather with the maintenance of open innovative and market conditions. The real danger of market concentration lies in creating barriers to potential innovative entrants and in concentrating the innovation process in too limited a range of organisations. There is no guarantee that the firms that have been successful innovators in the past are the most likely potential innovators for the future. An established market position is no guarantee of an ongoing capacity and willingness to innovate[14].

This suggests that the role of innovation policy is to ensure that conditions remain in place for the continued creation and exploitation of asymmetries of knowledge. In truly competitive markets, all established positions are open to challenge and it is this link between innovation and competition, which has proved to be the reservoir of economic growth. Thus, capitalism is necessarily restless, occasionally kaleidoscopic, and competition is at root a process for diffusing diverse discoveries, the utility of which cannot readily be predicted in advance. The market mechanism is simultaneously a framework within which to conduct innovative experiments, and a framework for facilitating economic adaptation to those experiments[15].

Increasing Returns and Roundaboutness in Knowledge Production

We have referred already to the inevitable presence of increasing returns in a knowledge-based economy, the fact that the returns to investments in innovation increase with the scale of their exploitation. That this rules out a perfectly competitive allocation of resources is well understood but there is much more to the phenomena than is suggested by this partial and static perspective. The point is a more general one. As Adam Smith understood so clearly,

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[14] I am very conscious that this leaves an unanswered (unanswerable?) question as to how much competition is desirable. If "red in tooth and claw" it may well destroy the longer term ability to maintain innovative progress. If too benign it may stimulate indolence and the pursuit of the quiet life. The system needs some grit to presume sufficient incentives to innovative which will vary from context to context. Unfinished business I am afraid.

[15] This theme of the experimental economy has been particularly important in Eliasson's work (1998). It has an

increasing returns applies to the generation of knowledge as well as to its exploitation precisely because of the increasing specialisation of bodies of knowledge and knowledge generating institutions. What we are observing in modern innovation systems is the increasing roundaboutness of production, not of material artefacts but of knowledge in general (Young, 1928).

It can be argued that two features shape the modern innovation process; namely, increasing complementarity of different kinds of knowledge together with increasing dissimilarity of these bodies of knowledge, a reflection of an increasingly fine division of labour in knowledge production. Innovating firms need to draw on and integrate multiple bodies of knowledge, whether scientific, technological or market based, produced in an increasing range of increasingly specialised contexts[16]. At the same time to understand the significance of and contribute to advances in these various kinds of knowledge is increasingly beyond the internal capabilities of the individual firm. Consequently, firms must increasingly complement their own R&D efforts by gaining access to externally generated knowledge and learn how to manage a wide spectrum of collaborative arrangements for knowledge generation (Coombs and Metcalfe, 2000). The consequences of this is that innovations take place increasingly in a systemic context with respect to the use of new technologies and their generation. How they do so is a question on the co-ordination of the division of labour in innovation systems.

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inevitable Austrian hue, that markets are devices to make the best of our limited knowledge (Rosenberg, 1990).

[16] Cf Grandstrand *et al* (1997) for evidence that large corporations are increasingly diversified in the technological fields which they employ, and more diversified relative to their product fields. See also Kodama's work on technology fusion (1995).

The Systemic Context

The focus of this perspective is best summarised in terms of the development of the science and technology infrastructure in the economy; an infrastructure that facilitates the intercommunication of existing research results and mutually shapes the future research agendas of different organisations. This infrastructure is a set of interconnected organisations to create, store and transfer the knowledge and skills that define technological opportunities (Edquist, 1997; Carlsson, 1997; Nelson, 1993). Many organisations are involved, private firms, universities and other educational bodies, professional societies and government laboratories, private consultancies and industrial research associations. Between them there is a strong division of labour and, because of the economic peculiarities of information noted above, a predominance of co-ordination by networks, public committee structures and other non-market mediated methods (Tassey, 1992; Teubal, 1996). The division of labour is of considerable significance for the degree to which the different elements of the system are connected. Different organisations typically have different cultures, use different "languages", explore different missions, operate to different timescales and espouse different ultimate objectives as our brief contrast between science and technology illustrated. As a consequence of these differences, knowledge is "sticky", it is partially unintelligible, it does not flow easily between different institutions or disciplines. Thus, there is a major problem to be addressed in seeking to achieve greater connectivity[17].

One strand of thinking in this area has been to emphasise the national domain of the science and technology infrastructure, and rightly so (Freeman, 1987, 1994; Lundvall, 1992; Nelson, 1993). Policy formulation and implementation is essentially a national process, despite an increasing range of policies at European level. However, there are good reasons to elaborate the national perspective both downwards and outwards. It is important to recognise that different activities have different supporting knowledge infrastructures so that a sectoral innovation system perspective becomes essential[18]. This is simply one way of recognising the specificity of the innovation opportunities facing firms (Carlsson, 1995). On the other hand, it is clear that the sectoral infrastructure frequently transcends national boundaries.

[17] cf, Andersen, Metcalfe and Tether (1998) and Green et al (1998) for further elaboration of the systems perspective. Also Edquist (1997) for a quite excellent overview of the current state of the art. Smith (1997) provides an excellent statement of an infrastructure perspective on innovation systems.

[18] There is a growing literature on regional innovation linkages in which an attempt is made to correlate innovation clusters with the processes of university based scientific activity. See Varga (1998) for a review and

Science and basic technology have always been understood as international systems and the same is increasingly true of technology more generally. Governments collaborate increasingly in major technology programmes, often in the defence area, and transnational companies typically have multiple technology development activities co-ordinated between different national infrastructures. Consequently, we begin to see the emergence of transnational technology development initiatives as exemplified by the European Framework Programme, which is now approaching its sixth stage, as well as much small-scale, inter-firm collaboration across national boundaries

This strand of thinking has been explored further by Gibbons and colleagues (1994), who draw attention to the emerging characteristics of new models of knowledge production which fit exactly with the view that innovation requires many kinds of knowledge for its successful prosecution. What they term "mode-2" knowledge is produced in the context of application, seeks solutions to problems on a transdisciplinary basis, is tested by its workability not its truthfulness and involves a multiplicity of organisational actors, locations and skills. Together this entails a distributed system for innovation with no necessary connection with traditional national or sectoral boundaries. Is it perhaps knowledge production for a global economy?

Innovation Policy and an Experimental Adaptive System

The central thrust of the argument so far is that the dynamic features of modern capitalist economies depend crucially upon their capacities as experimental systems; systems which continually generate new varieties of behaviour to be tested, adopted or rejected in the economic and social spheres. Innovation qua variety generation combined with the properties of selective processes makes competition an adaptive, evolutionary process. What has this to say about innovation policy if we are not to be guided by market failure? It is obvious that many policies impinge on the innovation process, in particular macro economic policy, competition policy and education policy, the latter in relation to the supply of scientifically, technologically and managerially qualified individuals[19]. My concern here is with innovation policies proper.

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empirical study of linkages in the USA.

[19] The prospect of EMU is certain to have rather profound implications for all of these background policies.

The initial step is to recognise the adaptive nature of the policy process and to contrast that with the optimal policy framework which is the corollary of the market failure approach. In this latter, the private sector generates the wrong incentive signals, the wrong relation between values and costs, which the policy maker corrects to guide decisions to their socially optimal values. We have already noted that this would require an unseemly amount of detailed knowledge and make the policy maker indistinguishable from the agents whose behaviours are to be influenced. Adaptive policy takes a more modest stance. It recognises the complex nature of the innovation process, that economic systems are capable of more than one kind of response to a given set of signals and incentives, that the outcomes of innovation processes are inherently unpredictable, and that it is the non- average, 'deviant' behaviours that drive economic change. Its concern is the design and formation of institutional arrangements that promote business experiments and which generate a greater degree of connectedness between knowledge generating and knowledge applying organisations.

To explore this further it is helpful to distinguish four specific elements that make up the innovation process. These are, the opportunity to innovate, as defined by the range of knowledge (scientific, technological and market) which is brought to bear; the resources available to develop and exploit the innovation; the incentives to develop the innovation; and, the capability to manage all of the diverse elements involved in innovating in a timely manner. The market failure perspective has emphasised the incentive and resource issues. By contrast, the systems failure perspective places the attention on the innovation opportunities facing firms and upon their management capabilities, including the capability to access and integrate external information with internal knowledge. This reflects directly the importance of the division of labour in knowledge production and the increasingly transdisciplinary and combinatorial nature of innovation processes. As explained above, firms must increasingly look beyond their formal boundaries for complementary knowledge, and this explains the recent rapid growth of innovation webs at many levels, from bilateral collaborations, to research clubs, to the formation of large-scale joint research institutions involving universities, government laboratories, users and suppliers as well as the innovating firms. These linkages enhance the knowledge base of innovating firms, and enable them to produce superior innovations more quickly than would otherwise be possible (Katz and

Martin, 1997)[20]. They are essentially devices for generating as well as for managing spillovers. From this perspective collaboration reduces R&D costs, it creates benefits from combining complementary knowledge bases and generally enhances the profitability of innovation. However, it is equally important to recognise that collaboration not only enhances profits, it may also dissipate the potential profits from innovation, costs and profits may be shared alike (Metcalfe, 1992). Shared knowledge is knowledge that rivals can use to compete against each other. Several features of R&D collaborations now fall into place. Those arrangements that improve profit enhancement are the ones that combine organisations with strongly complementary but dissimilar knowledge bases. Those arrangements that minimise the risks of profit dissipation, include the involvement of non-commercial organisations (e.g. Universities), of other vertically related members of the supply chain including customer firms, and of horizontal rivals who will exploit the shared knowledge in different niches or localities. Only if the collaboration is sufficiently "far from market", developing generic capabilities, are close horizontal rivals likely to be involved.

The Adaptive Policy Maker

Neither are innovation systems natural givens in the economic process, nor do sets of knowledge based organisations of themselves constitute an innovation system at any scale unless they co-ordinate their actions in the conduct of an innovation project, indeed, this is the insight contained in the quotation that starts this paper. Innovation systems are constructed for a purpose, to solve particular problems. How is an innovation system created? I suggest that three principles are at work. First, the firms, universities and other research organisations in an economy, the components of specific innovation systems, constitute a latent innovation resource not an innovation system. Secondly, that the connections that form an innovation system have to be articulated and the principal organiser of these connections is the private firm, for only the firm is in the position to combine all the many kinds of knowledge into a specific innovation sequence. Thirdly, the focal thread around which the connections are made is the set of unsolved problem sequences associated with the innovations in question. These problem sequences not only involve the production of knowledge but also the utilisation of existing knowledge and the combination together of

[20] An article in the Times Higher Education Supplement (25/9/98) writes of a collaborative venture between Rolls Royce, British Aerospace and three leading British university engineering departments to develop new design processes so that better aircraft can be brought to market more quickly.

different kinds of knowledge produced in different contexts. Moreover, as this set of unsolved problems evolves so must the structure and composition of the relevant innovation system change. New problems may require new kinds of knowledge and connections with new organisations if a momentum of innovation is to be sustained. Thus, the organisational ecology of a country's knowledge system is capable of being shaped into a plethora of operating innovation systems that connect with similar ecologies in other nations. What are national are the organisational ecologies and their institutional context of law, tradition and polity. What is systemic is the process of combining different organisations in the solution of specific innovation problems.

It follows that many of the collaborative arrangements that define a distributed innovation system can be interpreted as the temporary outcome of a process of spontaneous order. The interpenetrating webs of market and non-market arrangements are formed from below, they do not arise by chance alone but rather because there is commercial merit in knowing what is happening beyond the boundaries of the firm. Does this mean that there are grounds for policy concern? Can there be situations where the spontaneous order of system formation will not produce appropriate innovation systems? To the extent that the answers are in the affirmative we are in a position to argue that a central concern of the adaptive policy maker is to facilitate the self-organisation of innovation systems.

From a systemic perspective, failures can be of three general kinds: the system boundary is drawn in the wrong way, the organisations within the boundary are not appropriate as defined by the knowledge that they command, and the connections are not functioning correctly. Each of these is a problem associated with the division of knowledge labour and the increasingly roundabout knowledge production processes and their location is specialised organisations.

From the adaptive policy viewpoint, it follows that the principal task is to address these three kinds of system failure in order to stimulate the formation of innovation webs and to create bridging processes within those webs that better combine and utilise knowledge to further the innovation process[21]. First, missing components, the ecology of knowledge-based organisations may be deficient, important branches of knowledge may be missing from the

[21] The EC programmes beginning with ESPRIT in 1984 and culminating in the series of Framework programmes after 1987 fit exactly this model. They encourage collaborative research, pre-market in most cases, across national boundaries within the community. They are precisely policies for web formation.

national research effort. Here the appropriate response may be to set up research organisations to concentrate on the knowledge gaps. Second, missing connections, the incentives and opportunities may need to be created to encourage collaboration between different organisations. If innovation systems are to form spontaneously across public and private sectors, the policy maker has a role in enhancing mutual awareness of knowledge capabilities, and in removing barriers to collaboration that arise from differences in mission of different organisations. This is particularly so for research organisations located in the public sector and directed at public sector missions. These policies in relation to components and connections can only work through an understanding of the relevant communities of practitioners whether in firms, their suppliers or customers, higher education institutions or public and private research, development and design laboratories. A first policy requirement is to know this community, its institutions and the way they connect simply because it is through the community that policy effects will be channelled. A second policy requirement is to emphasise the guided nature of the growth of innovation related knowledge. Its accumulation is neither random nor set in fixed channels but proceeds within the constraints of cognitive frameworks which underpin the knowledge acquisition process. These cognitive frameworks provide a natural focus around which governments can stimulate network formation. Moreover, when knowledge changes, existing frameworks of relations may become obsolete and may actively resist reformation. Here, policy has a role to facilitate the transition to new innovation systems.

Market mediated transactions also play an important role in the system perspective. The recent privatisation of public research laboratories in Europe has encouraged the emergence of markets for knowledge and problem solving expertise within innovation systems, so that the boundary between market and network is fluid (Georghiou, 1998). The market in QSEs, research contracts and consultancies between firms and universities, payments for licences and, at the other extreme, mergers and acquisitions, are all devices used by firms to bring more knowledge within their walls[22]. Indeed the market for corporate control is a central market in an experimental economy. It is not simply to be seen as a device for disciplining poor management but as a device for combining complementary assets and for decombining them when they prove to be incompatible. The low cost facilitation of business experiments

[22] Howells (1997) shows that contract research and technology organizations in the UK have doubled their share of business R&D performed in the UK in the past ten years. In 1995 they accounted for 10% of total business expenditure on R&D.

is vital for a creative innovation process, and particularly relevant to the growth problems of the SME[23]. In the presence of limited supplies of entrepreneurial talent and substantial barriers to the growth of small technology based firms, the acquisition process can allow the assets built up in small companies to be exploited and developed more effectively in a large firm.

There is an important additional lesson contained in these principles. Governments will increasingly be unable to make national innovation policy decisions in isolation, policies will have to be co-ordinated and compatible for fear of making their country an unattractive location for technology development activities (Carlsson, 1995). The trend towards higher research costs has encouraged greater collaboration and major multinational firms in these sectors make significant investments in the national innovation systems they consider most relevant to their needs. In so doing they influence the development of these different national systems and of the universities within them. The attraction of high quality R&D activities in several high technology areas, pharmaceutical/medical and information technology, provide salient examples of this policy problem.

Having dealt with some general principles of innovation policy from a system failure perspective, I turn now to some specific examples drawn from UK experience and debate. The first is the UK Foresight programme; the second is tax subsidies for R&D.

[23] See Autio (1997) on the growth problems of new technology based firms and the view that their economic role is not to be judged by their growth but by their providing linkages in innovation webs.

Technology Foresight

There is no more appropriate indication of the switch in policy from matters of resources and incentives to matters of opportunities and capabilities than the adoption of a Technology Foresight Programme by the UK Government and indeed other governments (Laat and Laredo, 1998). Foresight activities have been defined as:

> "a systematic means of assessing those scientific and technological developments which could have a strong impact on industrial competitiveness, wealth creation and the quality of life" (Georghiou, 1996)

The process involved in conducting a large-scale foresight programme is precisely a matter of bridging and connectivity within a nation's science and technology base and between that base and its areas of application. Foresight is, from this view, a policy to encourage the self-organisation of multiple innovation systems. In particular, the crucial point about foresight proper is its inclusion of information about demand and market developments in its activity.

The process involved the creation of sectoral panels of "experts" that consulted on a wide basis with the relevant communities in industry, academia and government through regional workshops, a major delphi survey and numerous other activities[24]. Each panel has produced a report indicating the main forces for change and the policy issues which flow from the analysis as well as identifying the likely constraints on change. Without question, this is the most extensive consultation of industrial and scientific opinion which has ever occurred in the UK. It is because the development of modern technology is so heterogeneous with respect to its discipline base and institutional context that makes the sounding of opinion in the broadest possible fashion extremely important.

[24] A delphi study takes repeated samplings of opinion within a target group with feedback of the results to the participants between each sample, providing the opportunity to revise their opinions.

It is too early yet to come to clear conclusions concerning implementation indeed it is central to the exercise that the consequences may not be fully realised until a quarter century from now. It may also be that one outcome of Foresight will be a reallocation of resources within publicly funded science and technology in the UK. If so it will simply make transparent Weinberg's (1967) careful enunciation of external criteria for the support of science. Despite strong objections from the pure science lobby, the use of external criteria does not imply that pure science is to be transmuted into applied science (Vannevar Bush's demon it will be remembered) but rather the differential focusing of basic scientific work in relation to non-scientific objectives. Be that as it may, the principal lasting benefit of the exercise lies in the process and what the process does to the formation of commercial and academic strategies to promote innovation: to the creation of lasting networks between industry, government and the science and technology community, and to the emergence of coherent visions within those communities on complementary developments in science and technology. By a coherent vision is definitely not meant a consensus view about specific technologies or routes to innovation but rather an understanding of the breadth and interdependence between the uncertain opportunities open to a particular sector.

In summary, the Foresight Programme reflects an increasing concern with matters of systemic co-ordination in the innovation process: creating and supporting the technology support systems of particular groups of firms; and, bridging between those formal and informal institutions which interact in a specific technological area for the purpose of generating, diffusing and utilising technology (Carlsson and Stankiewicz, 1991; Carlsson, 1997). To create effective webs the policy maker must know the relevant communities of scientists and practitioners, and possibilities for commercial exploitation. The sequence of innovations which emerge and the firms which are successful are the outcomes of the process and are not a specific concern of the policy maker. Winners and losers emerge; as in any experimental process they are not and cannot be pre-chosen.

Tax Subsidies for R&D

The idea of providing general tax credits for R&D related activities is certainly not new (Metcalfe, 1995a) and has been adopted by several governments including those of Australia, Canada and the United States and most recently the UK. The general purpose is clear; the tax credit reduces the incremental cost of R&D spending and thereby provides incentives for private firms to spend more. As a policy, this certainly has the advantage that it focuses on the prime movers in the innovation process, and that does not involve governments in making market judgements about winners and losers. All that is necessary is that the company be profitable so that the tax credit has substance[25].

All of this implies that the policy must be designed carefully. Within any one sector, the effectiveness of the policy will depend on the rate at which returns to R&D diminish and on the elasticity of supply of R&D resources; the less elastic they are the more the subsidy will be dissipated in rents to QSEs, not in real R&D outlays. In particular, there is little point in subsidising the generation of new technological knowledge without at the same time subsidising the generation of the market knowledge. Secondly, drawing on our distributed innovation systems perspective, any subsidy should apply to externally acquired as well as to internally generated knowledge. The tax credits can be fashioned to encourage the formation of collaborative arrangements.

Tax subsidies fit well with our dynamic perspective on markets and they are complementary to the emphasis on other bridging policies. The effects are broadly distributed and no attempt is made to second guess the market. However, unless firms have a minimum in-house innovation capability their ability to participate in innovation webs will be severely limited. Tax subsidies may help firms gain and sustain that minimum capability while, conversely, the efficient working of innovation webs increases the pay-off to the R&D subsidy[26]. The two kinds of policy are complementary.

The final point that has to be addressed with any general subsidy policy such as tax credits, is it is bound to give rise to claims of waste and the misallocation of public revenues – even leaving aside the incentives for creative accounting. This is an important point because innovative, trial and error processes are inherently wasteful. Outcomes are not predictable ex ante, many projects fail and very few generate spectacular returns, as one would expect with any evolutionary process. There is no way to improve on this elemental indeterminacy and complexity of economic life. Our economics are adaptive experimental systems, increasing

[25] This is particularly problematic for small companies at the start-up stage. A market in tax credit certificates would certainly help in this regard.
[26] It is suggested that the industrial Research Association model widely utilized in the UK between 1920 and 1983 failed because the relevant firms never developed sufficient internal capability to understand the research carried out on their behalf.

the rate of experimentation requires that more failures are to be accepted along with more successes.

Conclusion

In this paper I have reviewed recent developments in innovation policy thinking and attempted to view them through the lens of new developments in thinking about the science, technology, competition relation. Here the fundamental insight is the experimental, evolutionary nature of a market and network economy. As Schumpeter aptly observed capitalism works by means of creative destruction, a process that is played out on a global scale. Patterns of international competition are ever changing and an advanced country must be ever aware of new opportunities and threats if its standard of living is to be sustained. Central to this must be the rate of innovative experimentation and I have suggested that a consistent thread to policy has emerged in the past twenty years based around a distributed innovation perspective. In this new approach, it is the institutional basis of innovation that is the focus of attention, rather than expenditure on research and development. I have called this the system failure perspective. From a political point of view this raises several interesting problems. Experimental economies have many failures as well as successes, blind variation means that a great deal of effort comes to nought and that patience is the sure companion to long-term success.

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